ISAL 2025
Article DOI: 10.26083/tuprints-00030859
16. International Symposium on Automotive Lighting
Darmstadt, 22. – 24. September 2025
DOI (proceedings): 10.26083/tuprints-00030825

Potential Energy Savings of Adaptive Driving Beam Headlamps Using ADAS Sensors by Environmental Aware Lighting Control

Yunji Heo[1], Hyeran Kang[2], Chan-Su Lee[2], Jaebeom Lee[1], Gilwon Han[1]

1: Hyundai Mobis, 17-2 Mabuk-ro 240beon-gil, Giheung-gu, Yongin-si, Gyeonggi-do

2: Yeungnam University, 280, Daehak-ro, Gyeongsan-si, Gyeongsangbuk-do

1. Abstract

This study proposes a strategy to reduce power consumption in vehicle lighting systems, particularly headlamps, as part of efforts to improve energy efficiency in electric and eco-friendly vehicles. Among the various electrical components in a vehicle, lighting systems consume a significant amount of power, with low beams accounting for approximately 52% of total lamp energy usage. Therefore, this study presents an integrated control strategy that dynamically adjusts the power consumption of low and high beams according to real-time driving conditions, aiming to reduce energy use while maintaining driver visibility and safety.

Experiments were conducted using simulation environments with 30 participants, based on three key variables: ambient illuminance, driving speed, and inter-vehicle distance. The results showed that in urban environments with high illuminance (above 50 lx), reducing low beam intensity to 25% did not compromise visibility or safety. At speeds above 80km/h, the use of high beams was found to be essential for maintaining sufficient visibility. Additionally, in scenario based on inter-vehicle distance, the presence of a leading vehicle allowed the Adaptive Driving Beam (ADB) system to further adjust light output. When applied to real-road conditions, low beam power consumption was reduced from 31.8W to 12.22W, achieving over 60% energy savings. This study is expected to be expanded through future research involving real vehicle testing and regulatory considerations.

Keywords: Matrix Head Lamp, Energy Saving, Ambient Light, Clearance, ADAS Sensor, Lighting Control Logic

2. Introduction

With the growing need to address global warming and the increasing adoption of electric vehicles, improving energy efficiency across the automotive industry has become a critical issue. In particular, optimizing power consumption for each component of eco-friendly vehicles is emerging as a key challenge. Among the various electrical systems in a vehicle, lighting systems account for a significant portion of total energy consumption, with low and high beams being among the most power-intensive components [1]. Specifically, low beams account for more than 52% of lamp energy usage, and their cumulative power consumption is substantial due to continuous operation during nighttime or low-light driving conditions.

Previous studies on low-power lighting have primarily focused on reducing light output [2] or using high-efficiency light sources such as LEDs [3]. However, these approaches are difficult to implement effectively without simultaneously considering driver visibility and safety. Therefore, this study aims to achieve both energy savings and visibility by dynamically controlling headlamps based on real-time driving conditions—ambient illuminance, vehicle speed, and inter-vehicle distance.

To this end, the study establishes various control scenarios and quantitatively analyzes their effects through simulation-based experiments. Furthermore, the applicability of these scenarios to real-road conditions is evaluated, aiming to make a practical contribution to the design of lamp systems for eco-friendly vehicles.

3. Research Methods

3.1 Experimental Setup

This study conducted experiments with 30 participants (aged 20s to 50s) based on three main control scenarios:

- Scenario 1: Low beam light output control based on ambient illuminance

- Scenario 2: ADB (Adaptive Driving Beam) control based on driving speed

- Scenario 3: ADB control based on inter-vehicle distance

The experimental environment was constructed using driving simulator software ANSYS AVxcelerate Headlamp (AVX) and AVSIMULATION SCANeR™ Studio. Participants performed visual detection tasks while their reaction time, obstacle detection distance, and accuracy were measured. If the obstacle detection distance was shorter than the required stopping distance, it was judged as "Not OK" due to insufficient time to avoid the obstacle, and the light output was adjusted to ensure proper detection distance (see Figure 1).

Additionally, an eye tracker was used to monitor the participants' gaze positions to determine whether they were actually performing visual detection.

The lighting system used a matrix beam composed of approximately 100 pixels, each of which could be individually dimmed (on/off). This allowed the system to reduce light in areas where visibility was unnecessary and maintain brightness where it was needed, enabling a highly flexible beam pattern configuration.

In addition to performance metrics, participants were asked to evaluate the visibility and subjective preference of each beam pattern configuration. This allowed for a comprehensive assessment of both objective detection performance and user-perceived comfort and effectiveness.

Figure 1: Experimental Environment and Visual Detection Task

3.2 Control Scenario Configuration

3.2.1 Low Beam Control Based on Ambient Illuminance

The driving environment's ambient illuminance was set to three levels: 10 lx (suburban roads), 30 lx (general urban roads), and 50 lx (high-illuminance urban areas).

Low beam brightness levels were configured as follows: 100% (based on Genesis luxury vehicle standard), 75%, 50% (legal regulation), 25%, and 0% (off).

The driving speed was fixed at 40 km/h, representing typical urban driving conditions. Evaluation metrics included the recognition rate of ground-level obstacles located in the driving lane and pedestrians positioned on the right sidewalk (see Figure 2(a)).

3.2.2 ADB Control Based on Driving Speed

Driving speeds were set to 50 km/h, 80 km/h, and 110 km/h. Low beams remained constantly on, while high beam brightness was varied across four levels: 0% (Low beam only), 20%, 45% (legal regulation), and 100% (Genesis luxury vehicle standard).

To minimize the influence of low beams, obstacles with a ground clearance of 70cm were placed, and recognition rates were measured not only in the vehicle's own lane but also in the adjacent left and right lanes (see Figure 2(b)).

3.2.3 ADB Control Based on Internal-Vehicle Distance

Driving speed was 110km/h, and inter-vehicle distances were set to 20 m, 40 m, 60 m, and 80 m. High beam brightness levels were configured to 25%, 50%, 75%, and 100%.

This scenario aimed to evaluate how the presence of a leading vehicle affects peripheral light control. To do this, obstacles with a ground clearance of 70cm were placed in the left and right adjacent lanes, and recognition rates were measured (see Figure 2(c)).

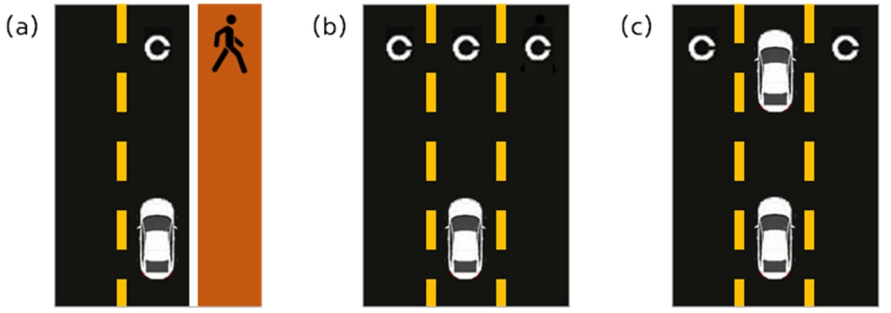

Figure 2: Configuration of the experimental environment (a) Scenario 1: low beam control based on ambient illumination (b) Scenario 2: ADB control based on driving speed (c) Scenario 3: ADB control based on internal-vehicle distance.

4. Experimental Results

Note: In Figures 3–5, the red dotted line indicates the braking distance on dry asphalt surfaces, the blue dotted line indicates the braking distance under snowy conditions, and the red circles represent the best-case scenarios where visibility and stopping distance were optimized under the given conditions. These references are provided once here to avoid repetition in individual figure captions.

4.1 Results of the Illuminance-Based Low Beam Scenario

As ambient illuminance decreased, higher low beam brightness was required. For instance, as shown in Figure 3(b), in a 30 lx environment, obstacles with a height of 15 cm were not reliably detected when the low beam brightness was below the legal threshold. Therefore, maintaining the legal regulation (50%) was sufficient to ensure a safe stopping distance in both 10 lx and 30 lx conditions.

In contrast, in the 50 lx environment, street lighting alone provided excellent recognition rates, and even when the low beam brightness was reduced to half the legal level, visibility was not compromised. Therefore, in high-illuminance urban environments (50 lx), especially during nighttime city driving, it is worth considering minimizing the low beam light output (see Figure 3(c)).

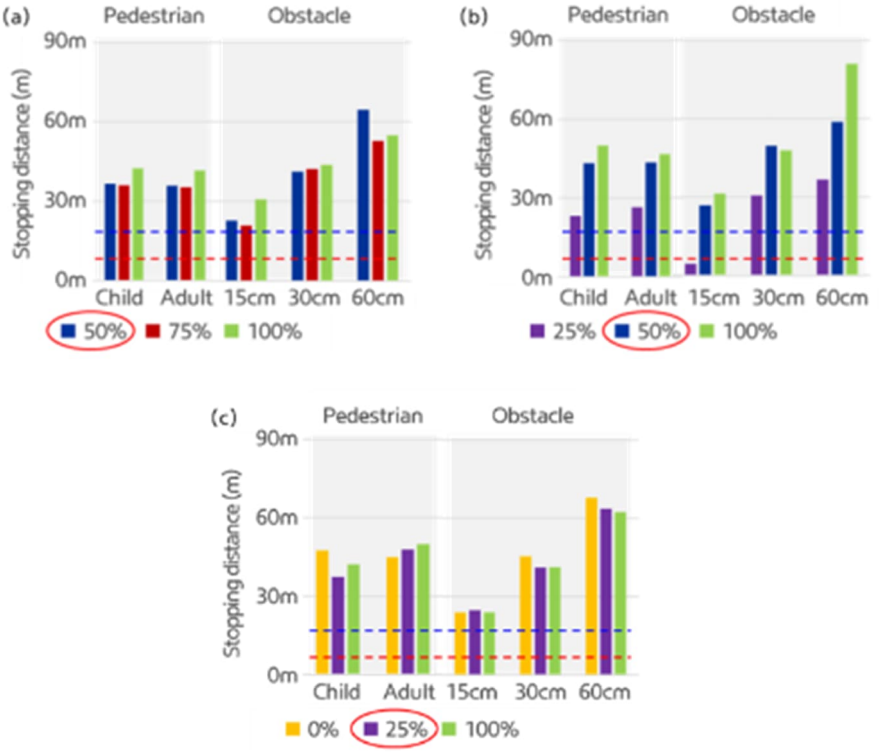

Figure 3: Comparison of stopping distances by object type according to ambient illumination and low beam light intensity variations. Braking distances at 40 km/h: 6 meters (dry asphalt), 21 meters (snowy asphalt). (a) a countryside road with an illuminance level of 10 lx (b) a regular street with an illuminance level of 30 lx (c) a commercial area with an illuminance level of 50 lx

4.2 Results of the Speed-Based ADB Scenario

At speeds below 50 km/h, low beams alone were sufficient to secure a safe stopping distance (see Figure 4(a)). In this speed range, the use of high beams was not necessary.

However, the use of high beams significnatly improved obstacle detection performance, particularly on the left side of the vehicle, compared to using low beams alone. The current legal standard for high beam brightness(45%) was found to be adequate under these conditions. For example, during snowy road driving at 80 km/h, high beams were necessary to maintain sufficient visibility (see Figure 4(b)).

At 110 km/h, even with high beams, maintaining a safe stopping distance became challenging, indicating a potential safety risk during snowy road (see Figure 4(c)).

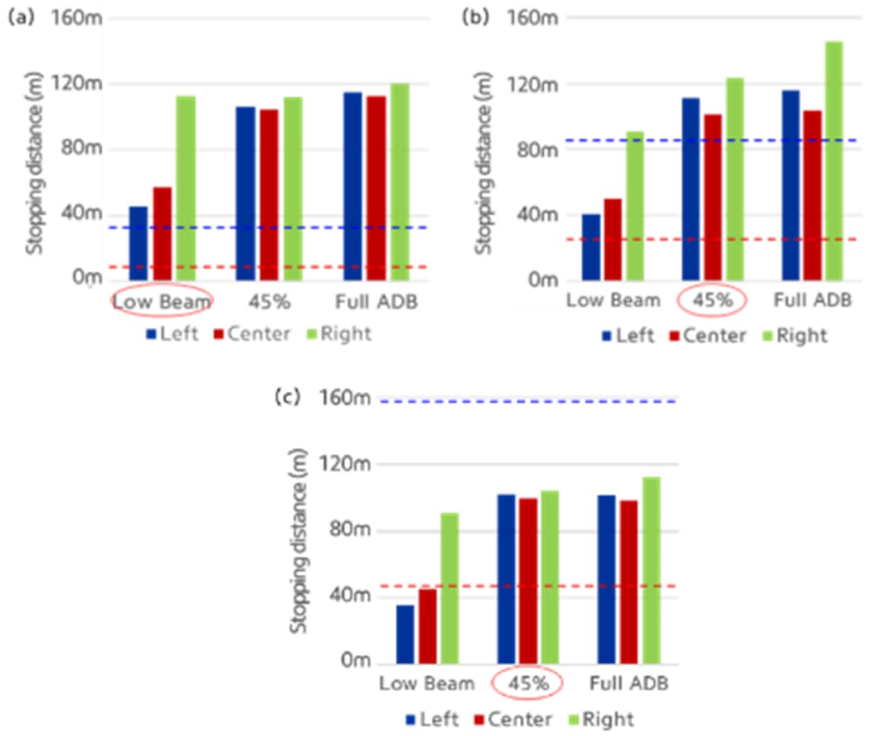

Figure 4: Comparison of stopping distances according to vehicle speed and ADB intensity variations. Braking distances in dry asphalt: 10m at 50km/h, 25m at 80km/h, 48m at 110km/h. Braking distance in snowy road: 33m at 50km/h, 84m at 80km/h, 159m at 110km/h. (a) driving speed of 50km/h (b) driving speed of 80km/h (c) driving speed of 110km/h

4.3 Results of the Inter-Vehicle Distance-Based ADB Scenario

When the inter-vehicle distance is short, the the driver's field of view is limited due to the presence of the leading vehicle, requiring brighter illumination of the surrounding area. In particular, at distances of 20 m, a significant portion of the driver's view is obstructed by the leading veihicle, and the ADB system must maintain a light output of at least 75% to ensure sufficient visibility (Figure 5(a)).

Conversely, when the distance exceeds 40 meters, the leading vehicle's headlights contribute positivlely to visibility, allowing the ADB system to reduce its own light output further. At distances between 40 m and 80 m, the low beams of the leading vehicle serve as supplementary lighting, mitigating visual obstruction and enabling the optimal light output to be reduced to as 25 (Figure 5(b)-(d)).

Additionally, during snowy road conditions, it is necessary to maintain an inter-vehicle distance of at least 80 m to ensure a safe stopping distance.

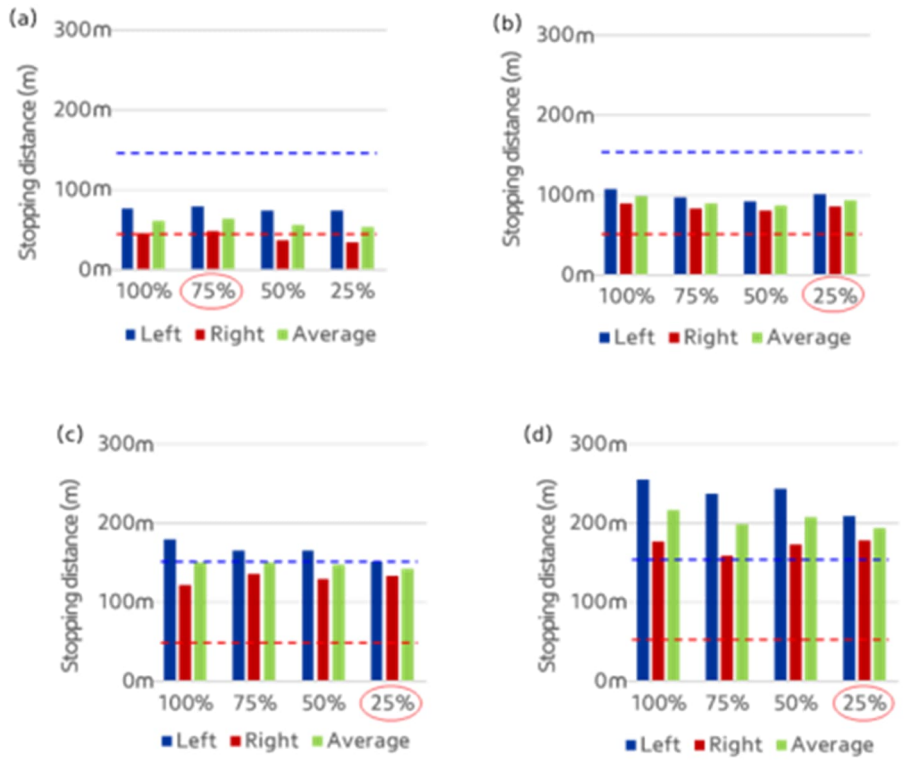

Figure 5: Comparison of stopping distances according to inter-vehicle distance and ADB light intensity variations. Braking distances at 110 km/h: 48m (dry asphalt), 159m (snowy asphalt). (a) a gap of 20 meters between vehicles (b) a gap of 40 meters between vehicles (c) a gap of 60 meters between vehicles (d) a gap of 80 meters between vehicles

5. Discussion

5.1 Analysis of Power Consumption Reduction

In accordance with South Korean streetlight installation regulations, road surface illuminance (lx) is classified based on road type and the number of lanes. The classification is as follows:

1. 10 lx: Alleyways or suburban roads at night (2 lanes or fewer)

2. 30 lx: General street lighting (between 2 and 4 lanes)

3. 50 lx: Bright street lighting in commercial or urban areas (4 lanes or more)

To estimate traffic volume per illuminance zone, total road length and the proprtion of each illuminance level were anlyzed, applying weights based on the number of lanes [4]. Table 1 summarizes the road length and traffic volume ratio for each zone.

Table 1: Traffic volume analysis by road type

Ambient Lighting Type	Road Length (km)	Traffic Volume Ratio (%)
10 lx (suburban road)	34,440.9	14.13
30 lx (regular street)	40,875.9	39.57
50 lx (commercial area)	3,667.9	46.30

Experimental results from Scenario 1 demonstrated that maintaining the legally regulated 50% low beam intensity, which corresponds to a power consumption of 15.9 W, was sufficient to ensure a safe stopping distance in both the 10 lx and 30 lx zones. Furthermore, in the 50 lx zone, a reduced intensity of 25%, with a power consumption of 7.95 W, was found to be adequate for maintaining visibility.

Based on these things, an adaptive low beam control strategy was proposed. By multiplying the traffic volume ratio (%) by the corresponding power consumption (W) for each zone, the total low beam power consumption under the proposed strategy was calculated. As a result, the overall low beam power consumption was reduced from 31.8 W to 12.22 W, achieving an approximate 62% reduction in energy consumption.

6. Conclusion

This study proposed a practical and intelligent headlamp control strategy that dynamically adapts to real-time driving conditions—such as ambient illuminance, vehicle speed, and inter-vehicle distance—to enhance energy efficiency without compromising driver safety.

By implementing and evaluating various control scenarios, including illuminance-based brightness adjustment, speed-dependent high beam activation, and adaptive beam modulation based on inter-vehicle distance, the research demonstrated the potential for substantial energy savings. Notably, the application of the proposed strategy under real-road conditions resulted in a reduction of low beam power consumption by approximately 50%, highlighting its practical value for improving the energy efficiency of electric and eco-friendly vehicles.

Furthermore, real-world analysis confirmed that the proposed control logic maintains sufficient visibility and safety while significantly reducing power consumption. These findings suggest that adaptive lighting control, when integrated with ADAS sensors, can serve as a key enabler for sustainable vehicle design.

Future work will focus on real vehicle field testing and broader validation across diverse driving environments to further refine the control logic and assess its long-term effectiveness and regulatory compatibility.

7. References

[1] C. Schmidt, M. Niedling, and W. Kösters, “Sustainable vehicle lights,” in *Proc. ISAL 2021 - Int. Symp. Automotive Lighting*, Darmstadt, Germany, pp. 719–729, 2021.

[2] A. Erkan et al, “Efficiency Enhancement Opportunities for Automotive Lighting Systems by Traffic Situation Analysis”, SIA VISION, 2022.

[3] S. Vogel, D. Peters, M. Niedling, and S. Völker, “Shaping new light distributions for different road lighting scenarios,” in *Proc. ISAL 2021 - Int. Symp. Automotive Lighting*, Darmstadt, Germany, pp. 432–441, 2021.

[4] KOSIS, “Lane Status by Road Classification.” [Online]. Available: https://kosis.kr/statHtml/statHtml.do?orgId=116&tblId=DT_MLTM_968&conn_path=I2. [Accessed: May. 23, 2024].